Center Innovation Fund: LaRC CIF

Holey Nanocarbon Architectures for High-Performance Lithium-Air Batteries

Completed Technology Project (2014 - 2018)

Project Introduction

The objective of this proposal is to develop 3-dimensional hierarchical mesoporous nanocarbon architecture using primarily our unique holey nanocarbon platforms (holey graphene and holey carbon nanotubes) as air electrodes for high performance lithium-air batteries (LABs), or "breathing batteries", with ultrahigh energy density.

Holey nanocarbon (HNC) platforms have recently demonstrated great promise in the application as high-performance electrodes for lightweight and compact supercapacitors (http://nari.arc.nasa.gov/ylin). These novel HNC structures exhibited not only micropores (< 2 nm), but also mesopores (2 - 50 nm) with controllable size and distribution. Mesopores of electrode materials are known to be critical to electrochemical energy storage. Different from conventional porous carbons, the HNCs have pores directly "carved" out from the sp^2 graphitic carbon surfaces of graphene and carbon nanotubes, allowing pathways for efficient ion transport even when the lightweight electrode is highly densified for volume reduction. While graphene and carbon nanotubes have shown significant advantages over conventional porous carbons in energy storage, HNCs have shown superior performance due to the improved porous structure and beneficial chemistry that occurs as a consequence of hole creation. A unique advantage of HNCs in comparison with other porous carbon/nanocarbon systems is that the chemistry at the hole edges allows for further chemical modification, for example, with metal or metal oxides that can provide a favorable environment for the requisite oxidation/reduction reactions in the battery.

LABs have a theoretical energy density of 3500 - 5000 Wh/kg, nearly 10 times that of conventional LIBs. Because the oxygen reactant on the cathode can be directly obtained from air, significant cost and weight reduction of the battery can be obtained. A set of challenges, very different from those encountered in supercapacitor research, are preventing the practical application of LABs. Increasing the catalytic efficiency of air cathode toward oxygen evolution to improve not only specific capacitance of air cathode but also its round-trip efficiency is a major challenge. Other major challenges include how to optimally induce the formation of resistive lithium peroxide discharge products with retaining the air diffusion, and how to maximize conductive contact between discharge products and air cathode for improved efficiency and cycling life.

Based on recent results from the current Principal Investigators, using HNC platforms as essential elements for 3D porous, conductive electrode architecture with high surface area, controlled mesopore distribution, and unique hole edge chemistry is proposed to have significant potential to improve electrode performance by benefiting the creation of active catalytic sites, alleviate the air blocking of the cathode for mass transfer, and improve the electrical contact of resistive discharge product and conductive carbon support. As a result, the HNC cathode-based LABs would have (1) reduced cell

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overpotential, (2) elongated cycling life, (3) improved discharge-charge power and energy densities, and (4) improved volumetric performance.

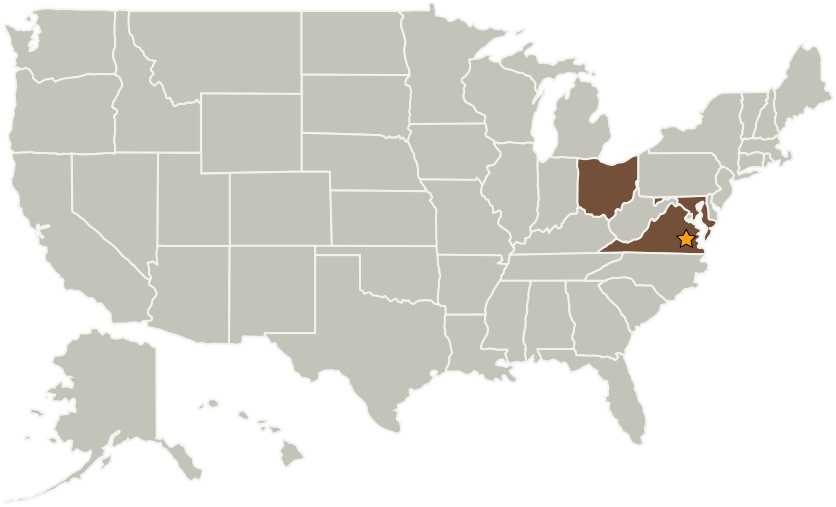
Anticipated Benefits

An estimated 80% weight savings for energy storage systems using LABs in comparison to the lithium ion batteries (LIBs) in future aircrafts represent a high potential payoff.

More significant weight savings are expected for smaller aircrafts (e.g. UAVs) where power systems consist of a larger fraction of the total weight.

Successful development of LABs will provide "high-specific-energy, human-rated Li secondary batteries." (TA3.2.1.1)

Primary U.S. Work Locations and Key Partners



Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Center / Facility:

Langley Research Center (LaRC)

Responsible Program:

Center Innovation Fund: LaRC CIF

Project Management

Program Director:

Michael R Lapointe

Program Manager:

Julie A Williams-byrd

Principal Investigator:

Yi Lin

Co-Investigators:

Liangbing Hu
Jae-woo Kim
John W Connell
Liming Dai

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Organizations Performing Work	Role	Type	Location
★Langley Research Center(LaRC)	Lead Organization	NASA Center	Hampton, Virginia
University of Maryland-College Park(UMCP)	Supporting Organization	Academia Asian American Native American Pacific Islander (AANAPISI)	College Park, Maryland

Primary U.S. Work Locations	
Maryland	Ohio
Virginia	

Images

Journal Cover (Nanoscale): Holey Graphene
An electron microscopy image of a holey graphene sheet
(https://techport.nasa.gov/image/18960)

Stories

Bulk Preparation of Holey Graphene via Controlled Catalytic Oxidation
(https://techport.nasa.gov/file/27603)

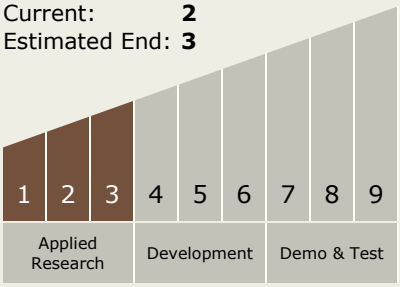
Holey Graphene Nanomanufacturing: Structure, Composition, and Electrochemical Properties
(https://techport.nasa.gov/file/27605)

Nitrogen-Doped Holey Graphene as Anode for Lithium Ion Batteries with High Volumetric Density and Long Cycle Life
(https://techport.nasa.gov/file/27606)

Oxidative Etching of Hexagonal Boron Nitride Toward Nanosheets with Defined Edges and Holes
(https://techport.nasa.gov/file/27610)

Technology Maturity (TRL)

Start: **1**
Current: **2**
Estimated End: **3**



Technology Areas

Primary:

- TX03 Aerospace Power and Energy Storage
  - TX03.2 Energy Storage
    - TX03.2.1 Electrochemical: Batteries

Scalable Holey Graphene Synthesis and Dense Electrode Fabrication Toward High Performance Ultracapacitors *(https://techport.nasa.gov/file/27604)*

Links

Bulk Preparation of Holey Graphene via Controlled Catalytic Oxidation *(http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=9120677.PN.&OS=PN/9120677&RS=PN/9120677)*

Single-Step, Solvent-Free, Catalyst-Free Preparation of Holey Carbon Allotropes *(https://www.google.com/patents/US20150104372?dq=Bulk+preparation+of+holey+carbon+allotropes&hl=en&sa=X&ved=0CCsQ6AEwAmoVChMI1-nLgOrWyAIVAioeCh2jiA8e)*